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Feature Article

Experimental floods in the River Spöl, Swiss National Park: Framework, objectives and design

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Abstract. Between 2000 to 2002, 11 experimental floods were released from 2 reservoirs separating different regulated segments of the Spöl River in the Swiss National Park. The riverbed of the Spöl had been altered substantially by regulated flows since energy production started in 1970. This 3-year experiment aimed to test whether an annual flood regime could restore riverine dynamics to this regulated river and, if so, how the floods must be managed in respect to a minimal but regular flow disturbance required to maintain riverine dynamics in a near natural state. This article outlines the framework, objectives and design of the experimental flood program on the River Spöl. The study involved a number of institutions controlling operational, economical, legal and ecological matters related to the floods, and was planned under the constraint that the floods would result in no increase in total water release during each year and no loss in total energy production. Concomitant cross-disciplinary environmental studies monitored the diverse impacts of each flood on the respective regulated segments. The various results, as shown in the accompanying reports, suggest that one or two annual high flows may be sufficient to enhance and sustain the ecological integrity of the Spöl over the long term.

Key words. Hydropower plants; reservoirs; energy production; residual flow; disturbance; riverine ecosystems; Switzerland; flow regime.

Introduction

Between 2000 to 2002, 11 experimental floods were released from 2 reservoirs separating different regulated segments of the River Spöl in the Swiss National Park. The main objectives of the floods were: a) to restore the riverbed which had been substantially altered by regulated flow since energy production started in 1970; b) to optimise the amount of water required for floods in respect to a minimum and regular disturbance regime needed to maintain the river system in a near-natural dynamic state; and c) to gain substantial scientifically-based results (i.e., a strong ecological rationale) for implementing a long-term regulated flood regime on the river. As a consequence, a number of environmental studies on the experimental floods were completed and are presented in the accompanying papers of this volume. Additionally, all institutions regarding the operational, economical, legal and scientific matters related to the floods were involved in the planning, including the Swiss National Park administration, the directorate of the Engadin Hydroelectric Power Company as well as government agencies of the canton Grisons. The Research Council of the Swiss National Park co-ordinated the project. The intent of this article is to outline the framework, objectives and design of the experimental floods from 2000 to 2002.

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The River Spöl: Description and dam construction

The catchment basin of the River Spöl (286 km^2) is situated in the central Alps, flowing through Italy and Switzerland. The National Park of Stelvio (Italy) and the Swiss National Park encompass a major portion (>80%) of the catchment. Near Zernez, Switzerland, the Spöl joins the River Inn, which eventually flows into the Danube. In the 1950s, Switzerland and Italy agreed to use the water from the Spöl for production of electricity; an issue strongly opposed by nature protection organisations and the Swiss National Park. The project went before a Swiss federal vote in 1956, being preceded by a fierce campaign for and against the project, and ultimately resulting with a majority vote in favour of the project. Construction of technical installations (e.g., dams and reservoirs) was completed between 1960 and 1969, and energy production started in 1970. Two major structures were built on the Spöl River: The dam at Punt dal Gall (reservoir of Livigno) and the dam at Ova Spin (reservoir of Ova Spin) (Fig. 1).

Both dams are double-arched concrete structures. Punt dal Gall dam is 130 m high, has a crest length of 540 m and a storage capacity of 164 million m^3, whereas Ova Spin dam is 73 m high, has a crest length of 130 m with a storage capacity of 6.2 million m^3. While the Livigno reservoir is used for storage with the aim of holding the plentiful summer water for use in the high demand winter season, the function of the Ova Spin reservoir is to act as a compensation basin. In fact, water collected from the main intake on the River Inn (cross-basin transfer) at the village of S-chanf, Switzerland, and transfered through a free-flow tunnel to the Ova Spin reservoir can either be pumped through the Ova Spin power station upstream to the Livigno basin or directly released downstream to the Pradella power station. During the typical winter operation, the water stored in Livigno reservoir is first used by the generators at the Ova Spin power station, where it then flows into the Ova Spin reservoir to be used at the Pradella power station (Fig. 1).

Both dams are located in the lower part of the Spöl catchment between the Gallo Valley and Livigno (Italy) and lower Engadin (near Zernez, Switzerland) (Fig. 1). In this region, the Spöl flows through a deep V-shaped canyon (i.e., canyon confined river). The two river segments influenced by the residual flow from the Punt dal Gall and Ova Spin dams have distinctive morphologies.

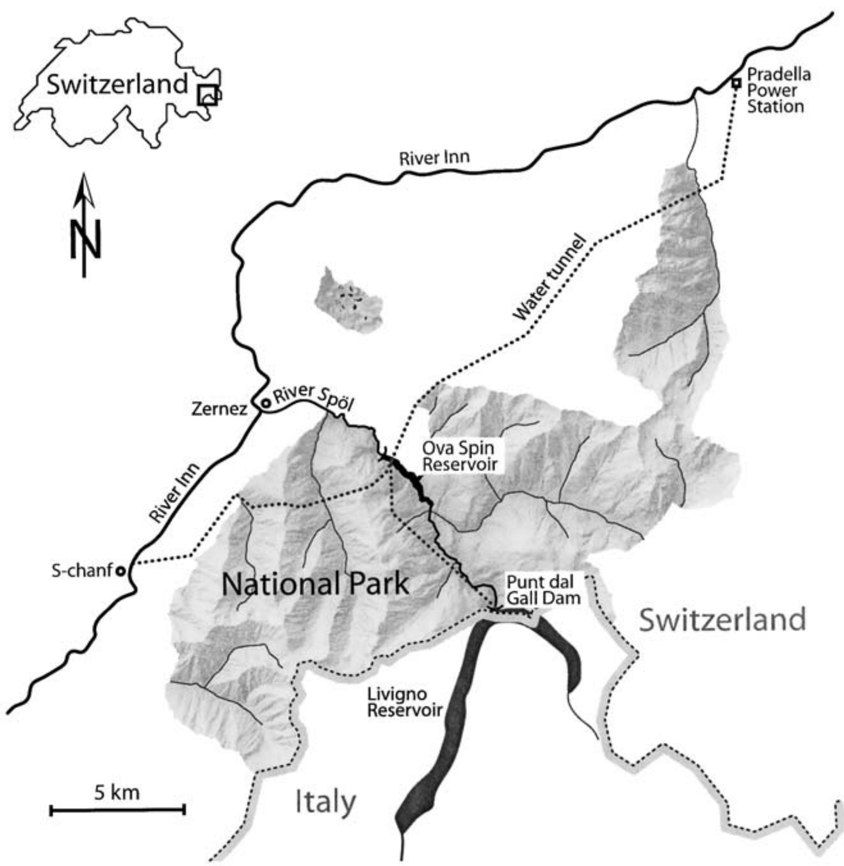

Figure 1. Map of the River Spöl from Livigno Reservoir (Italy) to its confluence with the River Inn (Zernez, Switzerland). The Spöl catchment is located in central Alps of Italy and Switzerland.

Between Punt dal Gall and Praspöl (confluence of the River Fuorn and the River Spöl at the head of the Ova Spin reservoir), a number of side-slope tributaries and scree slopes (talus) regularly transport sediments and organic matter to the Spöl. As a result of the residual flow regime, sediment input accumulated on the riverbed and constrained the waterflow, eventually forming low gradient and slow-flowing reaches upstream of these input zones. Below Ova Spin reservoir to the Spöl's confluence with the River Inn, the river flows through a deep, rocky gorge with few scree slopes and side tributaries until its confluence with the River Cluozza (Fig. 1). Sediments from the Cluozza accumulate on the riverbed before the Spöl flows through the alluvial plain by Zernez.

Table 1. Residual flow regime (m^3/s) in the two river segments below each dam on the River Spöl from 1970 to 1999 and from 2000 to 2002.

	Segment Punt dal Gall – Praspöl		Segment Ova Spin – Zernez	
	1970–1999	2000–2002	1970–1999	2000–2002
May 16 – September 30				
06:00 – 18:00	2.47			
18:00 – 06:00	1.0			
permanent		1.45	1.0	0.9
October 1 – May 15				
permanent	0.55	0.55	0.3	0.3
Annual experimental floods		2 at 10 m^3/s 1 at 30 m^3/s		1 at 15 m^3/s

The regulated flow of the Spöl

Before construction of the hydroelectric power installations in 1960, the average annual flow of the Spöl at Punt dal Gall fluctuated between 12.5 and 6.6 m^3/s with annual peaks ranging from 36 to 140 m^3/s (Fig. 2). During the period of construction (1960–1969), when water from the River Gallo was already diverted for use in Italy, the average annual flow still ranged from 4.4 to 8.8 m^3/s, with annual peaks from 14 to 70 m^3/s (Fig. 2; data from Punt dal Gall). Following completion of the dams in 1970, the residual flow for the section Punt dal Gall – Praspöl was set at an average flow of 1.0 m^3/s during the entire year (a total of 35 Mio m^3 per year). However, this residual flow was modulated to meet needs of energy production (i.e., greater water demand in winter and during the day in summer) and tourism in the National Park (aesthetic needs for flowing water during the day in summer) (Table 1).

In addition, the number and discharge of flow peaks decreased rapidly. For example, all of the flow peaks from 1969 to 1999 were singular events (Fig. 2), resulting from the technical needs for dam operation. Specifically, these high flows included the simulation of a catastrophic flow (125 m^3/s) in 1971, the emptying of Livigno reservoir (10.1 m^3/s) in 1985, and the flushing of the safety release gates at the base of Punt dal Gall dam (33 m^3/s) in 1990. Peak events rarely occurred when the Livigno reservoir was full in autumn, although overflow due to heavy rainfall at this time of the year occurred twice since commissioning of the dam (i.e., 42 m^3/s in 1979 and 45 m^3/s in 2000). Most peak flows <5 m^3/s can be explained by

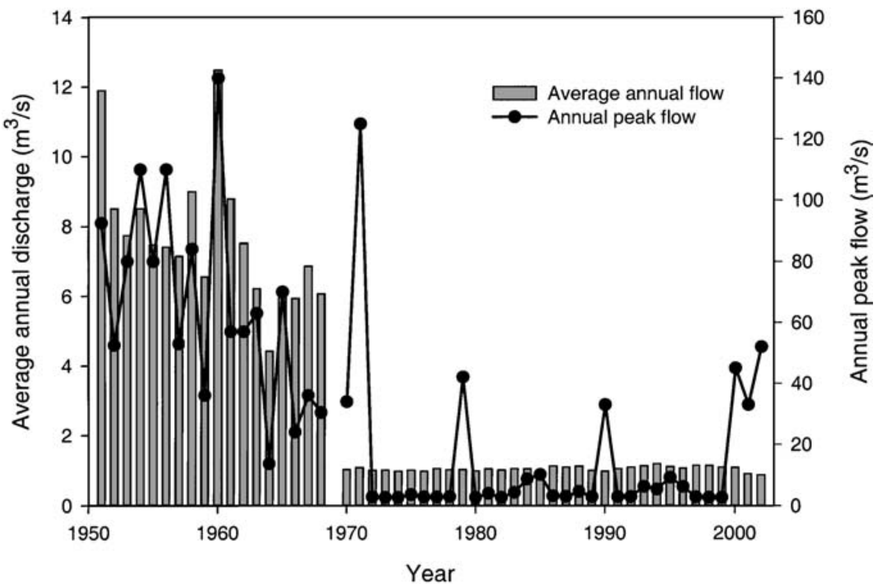

Figure 2. Average annual discharge and individual peak flows from 1951 to 2002 in the River Spöl at Punt dal Gall, Swiss National Park (Source: Swiss Hydrological Service (SHS), Federal Agency of Water and Geology, Biel, Switzerland).

local rainfall causing higher flows from lateral tributaries between the dam and the hydrological station downstream. However, the added flow from lateral tributaries typically is not relevant to the total flow of the system.

Lastly, the residual flow in the section Ova Spin – Zernez is lower than the upper section, being permanently set 1 m^3/s in summer and 0.3 m^3/s in winter (Table 1).

Ecological issues of the regulated flow regime

Because no ecological studies were conducted on the Spöl before and after the flow regulation was implemented in 1970, the effects of the altered flow regime on the ecology of the Spöl were anecdotal. However, a flushing of the safety release gates at the base of Punt dal Gall dam in 1990 (initiated by the Engadin Hydroelectric Power Company to ensure technical operations for water release) allowed for initiation of a project on the ecological consequences of flushing flows on the river downstream from the reservoir by the Swiss Agency of Environment, Forests and Landscape (Gerster and Rey, 1994). Studies within this project (e.g., sediment suspension, habitat characteristics, fish biology) were complemented by other studies (morphodynamics, water physico-chemistry, micro-organisms, vegetation) initiated by the Research Council of the Swiss National Park. The managed flood from Punt dal Gall on June 7, 1990, lasted 8 hours and had a peak flow of 30 m^3/s.

Environmental studies completed just before the artificial flood in 1990 confirmed that the regulated (residual) flow regime had substantially altered the structure and morphology of the riverbed. The most important reasons were three-fold: (1) Due to reduced flows, the loss of peak flows and the accumulation of lateral sediments, the river channel consisted of a sequence of laterally-dammed flat water reaches clogged by fines. Coarse substrate on the riverbed was colmated by fine sediments causing a reduction in the spawning grounds for fishes and allowing the development of vegetation and trees (mainly firs; *Pinus mugo*) in the riverbed; (2) Due to reduced current velocities and more constant flows, a dense coverage of mosses and filamentous algae became evident with similar increases in zoobenthic fauna adapted to such conditions such as the amphipod *Gammarus fossarum*; and (3) Because the water release from the Livigno reservoir is relatively cold, and rich in nutrients and plankton, the river Spöl downstream of Punt dal Gall exhibited similar characteristics as rivers downstream of lakes. The higher nutrient availability also was favorable for the riverine fauna.

The resulting river system deviated far from a comparable mountain river at similar altitude. Immediately following the managed flood in 1990, the ecological condition of the river between Punt dal Gall and Praspöl was clearly enhanced: fine sediments were flushed, dominant organisms such as mosses, filamentous algae and amphipods were reduced, and channel heterogeneity was greater. However, the flood had no significant influence on the developed riparian vegetation.

Enhancing the ecological integrity of the Spöl

Although the 1990 flood clearly had positive effects on the ecological conditions of the Spöl, the river character returned to its regulated state as before the flood within only a few years. These findings indicated that a single flood could not sustain the ecological integrity of the river over the long term, a result also confirmed by other studies (Patton et al., 2001). The lesson learned was that occasional single floods were not sufficient to restore and maintain more natural dynamic conditions in the Spöl. In order to prevent the development of poor habitat quality over time, the physical dynamics associated with flood disturbance must be continued annually on the river.

Because the Swiss National Park Authorities wanted to improve the ecological integrity of the River Spöl, they proposed to the Engadin Hydroelectric Power Company in 1996 to implement regular floods in the river segments downstream of the Punt dal Gall and Ova Spin dams. Initial discussions among the concerned authorities (Engadin Hydroelectric Power Company, Swiss National Park administration, government agencies of canton Grisons, and the Research Council of the Swiss National Park) showed that both the ecology and economy could profit from a managed flood program: the ecology through enhanced physical dynamics and improved biodiversity, and the power company by demonstrating an ecological improvement in a regulated ecosystem, this being necessary among other criteria to have its power production recognised as ‘green’ electricity (Truffer et al., 2001; 2003). Since the power company was obliged by Swiss federal authorities to conduct regularly operational checks of the safety release gates at the dams, there also was an operational benefit in combining these safety checks with the suggested flood water releases. It was also expected by the hydroplant operators that the periodic artificial floods could reduce sedimentation in the reservoirs.

Because no previous information was available on this kind of experimental flood design, the respective authorities agreed to implement the experimental floods over a three year period with the ultimate aim of maintaining a long-term flood regime in the regulated reaches of the River Spöl. The primary goals of the 3-year experiment included: 1) to test the feasibility of such flows from an economical and management perspective (i.e., no loss in energy production); 2) to understand (assess) the long-term ecological effects of an annual flood program; and 3) to optimise the amount of water used for flood and residual flows with specific reference to enhancing and sustaining the ecological integrity of the river.

Framework and design of the managed floods

Starting in 1996, experts from the respective authorities collaborated in the design of the managed flood regime for the two regulated river segments (Punt dal Gall – Praspöl and Ova Spin – Zernez). The flood program was guided by the following framework:

Energy production

The floods had to satisfy two ultimate conditions: no increase in the total water release over an annual cycle and no loss in energy production. It was necessary to reduce the residual flow in summer (May 15 – September 30) to save enough water for the artificial floods. The amount of flow reduced during this period also had to be ecologically justified. Essentially, a small reduction in the residual flow (0.1–0.3 m^3/s; see Table 1) resulted in ca. 3.4 million m^3 of water retained in the Livigno reservoir and ca. 1.2 million m^3 in the Ova Spin reservoir. The total of 4.6 million m^3 corresponded to 13.4% of the total annual residual flow for the Spöl. As mentioned above, the residual water releases, as dictated by the initial water use agreement among the authorities, are used to produce electrical energy in small hydroelectric plants at the base of both the Punt dal Gall and Ova Spin dams. Because these turbines and generators were engineered for flow capacities corresponding to the residual water releases, they could not cope with the increased flows from the floods. Hence the artificial floods had to bypass the turbines rather than being used for the production of electricity, and thus the released water for artificial floods would have meant a loss in production for the hydroplant owner.

Based on the average head at Punt dal Gall dam, 1 m^3 of water equals an average energy equivalent of 0.19 kWh. This same amount of water used with the higher head between Punt dal Gall and the Ova Spin power station yields an average energy output of 0.32 kWh. In other words, a given amount of water used directly at the base of the Punt dal Gall dam produces 59% of the energy yield when used with the higher head between Punt dal Gall and the Ova Spin power station. Consequently, there would be no production loss if 59% of the retained water in Punt dal Gall reservoir were used for energy production at the Ova Spin power station (Fig. 1). Similarly, transferring the hypothetical 1 m^3 of water used directly at the Ova Spin power plant for use with the much higher head between the Ova Spin reservoir through the Pradella power station to the Martina power station gains another 7.5%. Therefore, putting aside 7.5% of the water retained in the Ova Spin reservoir for power production at the Pradella power station also would result in no production loss (Fig. 1). Therefore, 2 million m^3 (59%) of the total 3.4 million m^3 of water retained in the Punt dal Gall reservoir plus 90,000 m^3 (7.5%) of the total 1.2 million m^3 of water retained in the Ova Spin reservoir, equaling a total of ca. 2.1 million m^3, could be used for compensation in production loss through flood releases. The result is 2.5 million m^3 of the total 4.6 million m^3 water retained each year would be available for flood program.

Operation

The floods had to be implemented with minimal disruption to the power company, thus the time frame was limited to working hours and days of the powerplant operators. Because the Engadin Hydroelectric Power Company also wanted to avoid the transport of sediments from the riverbed to the Ova Spin Reservoir, the maximum flood flow was set at 30 m^3/s based on experiences from the 1990 flood. The Company also was allowed to determine the exact time of each flood.

Ecology

The general time frame for the floods was set from June to September. The first flood in June took into account the ecology of the fishery. Based on the experience from the 1990 flood, the flow regime of each flood comprised three phases: 1) continual increase in flow to the maximum flow over 1–2 hours; 2) a constant maximum flow for 2–4 hours; and 3) continual decrease of flow for 3–4 hours (Fig. 3). In addition, the daily flow changes in residual flows were replaced with a constant residual baseflow. Using this framework, the new flow regimes were determined, including 4 annual floods: three 1-day

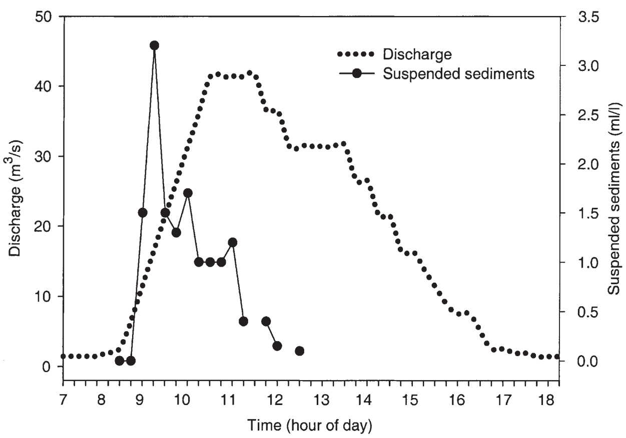

Figure 3. The discharge pattern (m^3/s) and suspended sediment (mg/l) in the Spöl at Punt Periv during the flood on 2 July 2002.

floods below Punt dal Gall dam and 1 flood below Ova Spin dam (Table 1).

The specific flow regime for each river segment was as below:

Punt dal Gall – Praspöl. Residual flow was reduced in summer by 0.285 m^3/s from 2.47 m^3/s (day) and 1 m^3/s (night) to a constant 1.45 m^3/s. The retained water provided for 3 floods each lasting approximately 8–10 hours. The floods consisted of a 10 m^3/s peak release in June, a 30 m^3/s peak release in July, and a 10 m^3/s peak release in August.

Ova Spin – Zernez. Residual flow was reduced by 0.1 m^3/s from 1.0 m m^3/s to 0.9 m^3/s, and 1 flood at 15 m^3/s was implemented in July.

The experimental flood regime was approved by the Swiss Federal Agency of Water and Geology (28 January 2000) and the government of the canton Grisons (15 February 2000).

Flood implementation: 2000 – 2002

For 3 consecutive years, 2000 – 2002, the artificial floods were implemented as designed above. Nevertheless, planned and effective flows differed because of technical difficulties (Table 2). For example, the maximum flow in July, 2000 (44.5 m^3/s) was much higher than expected due to problems with the water release mechanisms. Further, an additional flood occurred in autumn 2000 when heavy rainfall caused the Livigno reservoir to overflow. The floods were implemented as planned in 2001. The results from the various environmental studies in 2000 and 2001 indicated that one flood with a peak flow of 40 m^3/s was ecologically more effective than two floods at peaks of 30 and 10 m^3/s. As a consequence, the flood program was modified in 2002 (in agreement with the Engadin Hydropower Company) to 2 floods; one of these floods had a peak flow of 52 m^3/s (Table 2). In the section Ova Spin–Zernez, the managed floods – one flood with a maximum flow of 15 m^3/s every year in August – were implemented as planned.

Table 2. The experimental floods used in the River Spöl (Punt dal Gall – Praspöl), showing the planned and actual peak flows of each flood. Actual peak flows were a result of technical difficulties at the water release gates. The duration of each flood ranged from 8 to 10 hours. Source: HYDRA, SHS. * Overflow due to heavy rain; **short period at >50 m^3/s.

Date	Intended peak flow (m^3/s)	actual peak flow (m^3/s)
2000		
June 15	11.44	16.4
July 7	31.44	44.5
August 8	11.44	12.3
October 14–17	none	29.0*
2001		
June 13	11.44	11.6
July 7	31.44	30.9**
August 8	11.44	12.2
2002		
July 2	41.44	52.0
August 8	11.44	14.0

Accompanying environmental studies

The environmental studies (see accompanying papers in this volume) assessing the effects of the floods were intended to provide robust data towards optimizing the amount of water needed to fulfill ecological requirements. In this respect, two kinds of studies were initiated: a monitoring program and specific studies focusing on individual floods. The monitoring program began in 1996 during the initial planning of the floods. It aimed to document the morphological and ecological status of the river before and after the implementation of the floods over the long term. Ecological characteristics (e.g., benthos, channel morphology) were sampled annually at 9 sites in April and November: 2 in the section of Punt dal Gall – Praspöl, 4 in the section Ova Spin – Inn, and 3 in the River Fuorn, a tributary of the Spöl (Table 3). Studies on the effects of individual floods on the ecology of the river were primarily focused in the section Punt dal Gall – Praspöl (Table 3). These studies concentrated on general limnology, fisheries, habitat characteristics, river morphology and structure, water quality, and riverine/riparian vegetation (Jakob et al., 2003; Mürle et al., 2003; Ortlepp et al., 2003; Robinson et al., 2003; Uehlinger et al., 2003).

All studies were conducted to provide complementary information. Spatially, studies were completed in common locations (e.g., SP1, SP2, SP3), transects (T) and sections (PdG, PP) (Table 3). Temporally, studies were conducted at pre-defined sampling times, intervals, and duration. Further, all participating groups followed a common pre-defined sampling design. In addition to this general framework, some additional investigations were completed to gain more detailed information on organism drift (Aebischer, 2001), and longitudinal impacts on algae and macroinvertebrates (Jakob, 2001; Jakob et al., 2003). Other studies provided reference data on bed sediments (sediment cores) in the reservoirs and river channel (Ortlepp et al., unpublished data), temporal dynamics on an adjacent tributary (Robinson et al., 2002; 2003; Uehlinger et al., 2003), and the influence of reservoirs on the genetic structure of mayflies (Monaghan et al., 2001).

Table 3. Parameters measured and time series for each investigation regarding the experimental floods on the river segment between Punt dal Gall – Praspöl.
B = before experimental floods, A = after experimental floods, J = June, Ju = July, Au = August.
Sampling Locations are S1 = 150 m downstream from the dam, S2 = 250 m downstream, S3 = Punt Periv at 2.3 km downstream. Cartography and fishery sections (400 m long) are PdG = Punt dal Gall, PP = Punt Periv. Cross-sections are T = transects. Fisheries and vegetation plots also assessed in 1990.

Investigations	2000					2001					2002				Location
	B	J	Ju	Au	A	B	J	Ju	Au	A	B	Ju	Au	A	
Basic monitoring program (since 1996)															
benthos	x				x	x				x	x			x	S1, S3
morphology	x				x	x				x	x			x	S1, S3
Flow															
continuous															PdG
water level		x	x	x			x	x	x			x	x		S1–S3
Riverbed morphology and structure															
cartography	x				x	x				x	x			x	PdG, PP
sediment	x				x	x				x	x			x	S1, S2
cross sections	x				x	x				x	x			x	T (n=12)
Water quality															
sediments		x	x	x			x	x	x			x	x		S1-S3
physico-chemical		x	x	x			x	x	x			x	x		S3
temperature		x	x	x			x	x	x			x	x		S3
oxygen			x	x			x	x	x			x	x		S3
Limnology															
invertebrates		x	x	x			x	x	x			x	x		S3
periphyton		x	x	x			x	x	x			x	x		S3
drift		x	x	x			x	x	x			x	x		S3
Fisheries															
electro-fishing					x									2003	PdG, PP
spawning grounds					x				x					x	PdG, PP
Vegetation															
plots					x									x	various
transects					x									x	T (n = 4)
photo documentation					x									x	n = 49 locations

Conclusions and outlook

Framework

Ten years have passed since the 1990 flood and the experimental flood program was initiated in 2000. The historical legacy of the 1950s conflict between the Swiss National Park and Engadin Hydropower Company over the use of the Spöl required some time to settle. Thus today, the healthy partnership between the Park authorities and the Hydropower Company to implement the flood program on the Spöl can be considered an outstanding success. Essentially, 3 circumstances favored the implementation of the flood program: 1) the fact that the hydropower production clearly altered the river ecosystem in the National Park facilitated the need for a common solution by end users; 2) the water necessary to change the flow regime below the dams was available and cost neutral (this important factor is not possible in every case); and 3) the use of experimental floods aligned well with the current paradigm of restoring the natural flow regime in rivers (Poff et al., 1997), thus the program was scientifically timely for researchers across different disciplines.

Ecological issues

As confirmed by the various environmental studies on the floods (Mürle et al., 2003; Ortlepp et al., 2003; Robinson et al., 2003; Uehlinger et al., 2003), annual managed floods could be used to improve the ecological integrity of the River Spöl. These findings resulted in all interest groups to agree to continue the flood program for the river, although additional questions still need answered in regard to the long-term ecological needs of the river. Presently, managers believe that a single annual flood of >40 m^3/s may be sufficient to maintain riverine dynamics. This management scheme will be implemented and monitored in 2003. Further, managers suggest that the present residual flow should reflect better the natural seasonal fluctuations in flow, thereby potentially further enhancing the ecological integrity of the river system. Lastly, the experimental results have suggested that managers should use an adaptive management policy to sustain the ecological effectiveness of managed floods over the long term. For example, managers should be flexible in respect to the interval and quantity of floods as ecological conditions in the river change over time.

Economic and operational perspectives

As mentioned earlier, the owner of the power plant expected that the artificial floods would possibly reduce the sedimention rate in the Punt dal Gall and Ova Spin reservoirs and thus extend the time period between necessary flushing flows. This expectation, however, was not realized. Because the lake sediments near the dams consist of extremely fine, silty and compacted material, the flow releases only resulted in a funnel-shaped depression just at the entrance of the emergency release gates. This observation was confirmed by the fact that suspended sediments were high for a short period (typically <1 hour) during each flood (Fig. 3). Consequently, although the floods can be implemented during the required operational tests of the release gates, the major gain by the Hydropower facility is through an improved environmental image rather than any tangible benefit – at least for the time being. For example, it is well-known that the market value of environmentally-sound electrical production is increasing. As such, the Engadin Hydropower Company recently certified its production as environmentally sound through the Swiss label *naturemade basic.* Further, the flood program was possible primarily because there was no loss in power production. From a global ecological perspective, a loss in production (essentially pollution-free hydrologic production) actually would have had a negative impact because it would have had to be replaced with another form of production, all with higher emissions of green-house gases. We believe this program demonstrated the positive results of combining ecological interests (local and global) with economic interests, thereby providing an example for other river systems having a similar framework.

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